Harmful Algae 61 (2017) 80–86

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

Possible spreading of toxic *Alexandrium tamarense* blooms on the Chukchi Sea shelf with the inflow of Pacific summer water due to climatic warming

Masafumi Natsuike[a,*], Kohei Matsuno[b], Toru Hirawake[a], Atsushi Yamaguchi[a], Shigeto Nishino[c], Ichiro Imai[a]

[a] Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan
[b] Australian Antarctic Division, 203 Channel Highway, Kingston, Tasmania 7050, Australia
[c] Japan Agency For Marine-Earth Science and Technology, 2-15 Natsusihima-cho, Yokosuka, Kanagawa 237-0061, Japan

ARTICLE INFO

Article history:
Received 19 March 2016
Received in revised form 27 November 2016
Accepted 27 November 2016
Available online xxx

Keywords:
Alexandrium tamarense
Chukchi sea shelf
Climatic warming
Pacific summer water
Sea ice reduction
Spatial distribution
Temporal distribution

ABSTRACT

A high abundance of resting cysts of the toxic dinoflagellate *Alexandrium tamarense* was recently reported in the vast continental shelf of the Chukchi Sea in the Arctic Ocean, suggesting that the species is widespread in the shelf. Nevertheless, little is known about the occurrence of *A. tamarense* vegetative cells in the water column of the arctic. Sea ice reduction and the inflow of Pacific summer water (PSW) through the Bering Strait have recently increased owing to warming in the shelf. To determine the spatial and temporal distributions of *A. tamarense* in the Chukchi Sea shelf and their relationship to the inflow of PSW, field samplings were conducted in the Chukchi Sea and north Bering Sea shelves three times during the summer of 2013 from July to October. Vegetative cells of *A. tamarense* was detected in both shelves at all sampling periods with a maximum density of 3.55×10^3 cells L^{-1}. This species was also observed at the station at 73°N, indicating the northernmost record of this species to date. The center of the *A. tamarense* distribution was between the north Bering and south Chukchi Sea shelf during the first collection period, and spread to the north Chukchi Sea shelf during the second and third collection periods. The species occurrences were mainly observed at stations affected by the PSW, especially Bering shelf water. Water structure of PSW was characterized by warmer surface and bottom water temperatures, and increased temperatures may have promoted the cell growth and cyst germination of *A. tamarense*. Therefore, it is suggested that an increase in the PSW inflow owing to warming promotes toxic *A. tamarense* occurrences on the Chukchi Sea shelf.

1. Introduction

The toxic dinoflagellate *Alexandrium tamarense* (Lebour) Balech is mainly distributed in temperate and subarctic coastal waters (Steidinger and Tangen, 1997; Lilly et al., 2007). The species, however, has recently been detected in colder arctic regions. Its resting cysts and vegetative cells are found in the coastal areas of the western Bering Sea (Selina et al., 2006; Orlova et al., 2013). Baggesen et al. (2012) and Burrell et al. (2013) first reported the contamination of scallops and mussels with *A. tamarense* from the west coast of Greenland and Iceland. Furthermore, abundant *A. tamarense* resting cysts have been found in the bottom sediment surfaces from the vast continental shelves of the eastern Bering Sea and Chukchi Sea (Gu et al., 2013; Natsuike et al., 2013). These observations suggest frequent bloom occurrences of *A. tamarense* in the arctic region.

Chukchi Sea is a marginal sea of the Arctic Ocean with a continental shelf in which the water depth is less than 50 m; it connects to the north Bering Sea through the Bering Strait (Fig. 1). The occurrence of *A. tamarense* in this area was originally reported in the coastal area near Point Barrow in the Chukchi Sea during the summer (Bursa, 1963). Since then, observations have been quite limited in the Arctic Ocean, including the Chukchi Sea. Neither Horner (1984) nor Okolodkov and Dodge (1996) reported species occurrences in the Beaufort Sea and larger areas in the Arctic Ocean during the summer. The dominance of *Alexandrium* sp., however, was recently reported on the slope of the north Chukchi Sea shelf

* Corresponding author. Present address: School of Environmental Engineering, Tokyo Institute of Technology, 2-12-1-M1-4 Ookayama, Meguro, Tokyo 152-8552, Japan.
E-mail address: natsuike.m.aa@m.titech.ac.jp (M. Natsuike).

http://dx.doi.org/10.1016/j.hal.2016.11.019
1568-9883/

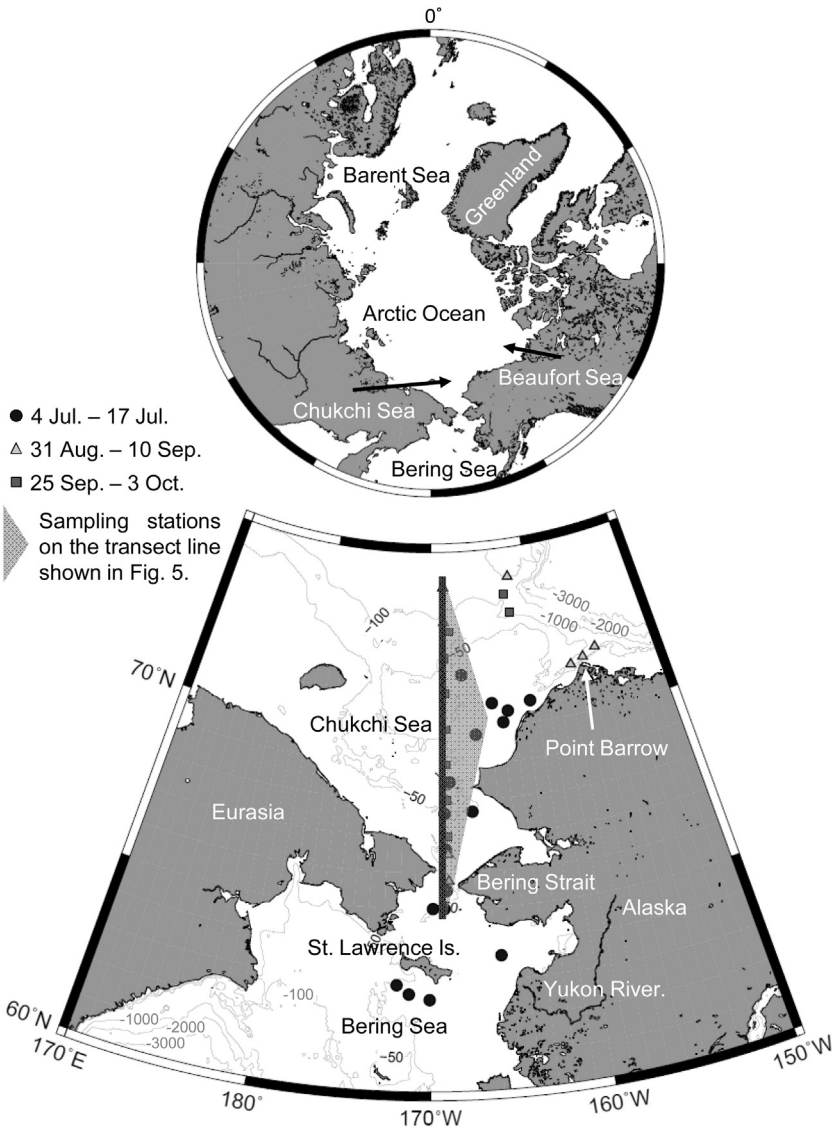

Fig. 1. Locations of sampling stations in the north Bering Sea and Chukchi Sea shelves during the summer of 2013. Black circles (●) indicate the stations included during the first period (July 4–Jul 17). The grey triangles (△) and squares (■) indicate stations included during the second sampling period (August 31–September 10) and third sampling period (September 25–October 3), respectively.

during the summer of 2002, yet the precise species was unknown (Sukhanova et al., 2009). Furthermore, the occurrence of *A. tamarense* was noted in the Chukchi Sea shelf during the summers of 2002 and 2003 (Walsh et al., 2011), and abundant depositions of *A. tamarense* resting cysts were found in the bottom sediment surfaces from the continental shelves of the eastern Bering Sea and Chukchi Sea (Gu et al., 2013; Natsuike et al., 2013). Thus, the occurrence of *A. tamarense* vegetative cells in the coastal areas of Chukchi Sea and abundant deposition of *A. tamarense* cysts in sediment of Chukchi Sea shelf have been confirmed (Bursa, 1963; Gu et al., 2013; Natsuike et al., 2013). Nevertheless, the temporal and spatial distributions of the *A. tamarense* vegetative cells in water column are yet unclear in the Chukchi Sea shelf.

Recently, increasing inflows of Pacific water from the Bering Strait to the Chukchi Sea shelf have been observed during the summer, along with drastic reductions in sea ice owing to warming; these inflows increase the water temperature in the shelf (Shimada et al., 2006). Thus, recent drastic sea ice reductions by warming are suspected to affect *A. tamarense* occurrences in the shelf. Nevertheless, little is known about the relationship between *A. tamarense* populations and the inflow of Pacific summer water (PSW). In the present study, field observations were conducted to clarify the temporal and spatial distributions of *A. tamarense* vegetative cells on the Chukchi Sea shelf during the summer and examined the relationships between species occurrences and PSW inflow.

2. Materials and methods

Field observations in the north Bering Sea to the Chukchi Sea were conducted to track sea ice melting during three periods in the summer of 2013. During the first observation period from July 4 to July 17, the T/S *Oshoro-Maru* was used at 17 stations from the north Bering Sea, including the station located south of the St. Lawrence Island, to south of the Chukchi Sea shelf (Fig. 1). South of St. Lawrence Island is known as a polynya, which is an open water area that is surrounded by sea ice during the winter. The second (from August 31 to September 10) and the third (September 25–October 3) observations were performed using the R/V *Mirai* at 10 and 9 stations in the Chukchi Sea shelf and slope, respectively (Fig. 1). Vertical profiles of the water temperature and salinity were obtained using a CTD, and seawater samples were collected at